



A Driving Force-Pressure-State-Impact-Response (DPSIR) tool to help waste pickers' cooperatives self-evaluate their environmental and economic performance

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ABSTRACT

Cooperatives of waste pickers play a critical role in municipal solid waste management, contributing to public health, sanitation, and the environment by promoting resource circulation and reducing the amount of recyclable waste disposed of in landfills. Despite this, the majority of cooperatives lack an organized physical infrastructure and operational protocols for integrated waste management, which includes the stages of sorting, classification, processing, and marketing recyclable waste. In this work, an optimized survey was developed to assist waste pickers' cooperatives in self-assessing their social, environmental, and economic performances. A questionnaire with nine dimensions was developed and automated to connect 16 driving forces (D), 74 pressure indicators (P), 23 states (S), 35 impacts (I), and 38 responses (R). The only action required was to choose each pressure indicator and apply the appropriate score level based on the cooperative's data analysis. The procedure eliminates subjective interpretation and identifies all indicators that require further consideration and discussion. As a result, the cooperative is able to propose highly targeted improvement measures. To demonstrate the benefits of the tool, the survey was applied in a waste picker's cooperative in a municipality in Brazil.

1. Introduction

Effective waste management is a global issue, particularly in urban areas where financial, physical and human resources are limited. Inadequate management has a clear detrimental effect on the population's quality of life, public health, and the environment due to pollution of the air, soil, and water caused by the emission of gasses and leachates from waste decomposition. In this scenario, Brazil generated 79 Mt of municipal solid waste (MSW) in 2019, a 23% increase over the amount generated in 2010. The average *per capita* generation increased from 348 to 369 kg/year/person (0.95 to 1.01 kg/day-person) during this time period. In 2019, the collected fraction of MSW reached 72.7 Mt, accounting for 92% of the total generated (ABRELPE, 2020).

Despite promising trends in comparison to other low- and middle-income countries, Brazil faces a number of complex challenges in providing an environmentally acceptable and efficient solid waste management program in urban areas (Aparcana, 2017). Part of the complexity stems from the country's vast territorial extent (5th in the world), its large population (6th in the world) that is unevenly distributed across its

five regions, and from infrastructure disparities caused by demographic, geographic, and economic factors.

The MSW is made up of residuals and byproducts from domestic activities, street sweeping, and household and public cleaning. Thus, the separation, storage, collection, transportation, processing, recovery, and disposal of these fractions are all part of municipal solid waste management (MSWM). It entails the collaboration of many stakeholders within the municipality, as well as the population and local governments, for the relevant activities (Gonçalves et al., 2018; Kato et al., 2020).

In Brazil, the MSW is separated into two broad categories: recyclables and non-recyclables (organic material). The cycle of reuse, recycling, and composting is fed by the selective waste collection (SWC). This activity is carried out via door-to-door and Voluntary Delivery Points (VDP) by public authorities. Since the approval of the National Solid Waste Policy (NSWP), Law 12,305/2010, (Brazil, 2010; Fattor and Vieira, 2019), the inclusion of the informal sector through associations and cooperatives has become increasingly incentivized throughout the country (Alfaia et al., 2017). However, integrating recyclable material pickers into the overall MSWM system is still a significant chal-

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lenge, often due to their lack of training, which is essential to deal with their health and safety in the operation of associations and cooperatives (Aparcana, 2017; Gonçalves et al., 2018). In Brazil, the SWC is practiced inconsistently. In 2018, 1227 municipalities implemented effective selective collection, serving 35 million people but accounting for only 17% of the Brazilian population (CEMPRE, 2019). In 2019, 4070 (73.1%) of the country's 5070 municipalities implemented some form of selective collection, with the South (90.9%) and Southeast (89.7%) showing the most encouraging trends (ABRELPE, 2020).

There are three primary strategies for selective collection as described by Fattor and Vieira, (2019): i) Door-to-door waste pickers: these are individuals or organizations that collect recyclable materials door-to-door. Typically lack organized or private space, and all street-collected materials are sold to intermediaries such as recycling trades; ii) Waste dumpers: These individuals are those who work in open dumps. They separate recyclables from the entire amount of material collected during the city's garbage collection, typically in unsanitary and unsafe conditions; iii) Waste pickers' cooperatives (WPC): these are member-owned, democratically-controlled enterprises of groups of waste pickers that separate recyclables from an initial mass of waste. The material can come from either one's own collection or a city's curated collection. The significant difference lies in the distribution of earnings among all group members.

Cooperatives, particularly in Brazil, Argentina, Colombia, India, and South Africa, have played an important role in integrating waste pickers into formal waste management chains. Recent data indicates that over a quarter million people in Brazil are engaged in waste picking (ILO, 2019). In 2020, Brazil mapped 1829 cooperatives and picker associations in 986 municipalities. Within the recyclables category, these cooperatives recovered 354 kt, including 54.0% paper, 21.5% plastic, 14.7% glass, and 9.8% metals and other materials, for a total revenue of R\$139 million. (ANCAT, 2020).

On a social level, cooperatives are critical to the implementation of the National Solid Waste Policy in Brazil. Waste pickers make significant contributions to public health, sanitation, and environment by promoting resource circulation and reducing the amount of recyclable wastes sent to landfills (Ma and Hipel, 2016; Marelllo and Helwege, 2018; ILO, 2019). Nonetheless, the majority of cooperatives lack an organized physical infrastructure and operational protocols for integrated waste management, including the stages of sorting, classification, processing, and marketing recyclable waste (Fattor and Vieira, 2019; Bercegol et al., 2017; Zolnikov et al., 2018). Numerous cooperatives have spaces that, if managed more effectively, could result in increased productive capacity, ensuring autonomy, competitiveness and financial and/or administrative independence to them. To do this, periodic assessments within the cooperative are required to identify critical points in the process in order to generate greater income while reducing environmental impacts (Ibáñez-Fóres et al., 2019, 2021).

2. The driving force-pressure-state-impact-response (DPSIR) framework

The Organization for Economic Co-operation and Development (OECD) proposed in 1993 the Pressure, State, and Response (PSR) framework (OECD, 1993). This methodology was intended to generate indicators of sustainable development in three categories: Pressure (P), State (S), and Response (R). The PSR framework was based on a causality concept: human activities exert *pressure* on the environment, altering the quality and quantity of available resources (*state*). Adaptive, preventative, and mitigating actions are taken by society in *response* to these changes. The European Environment Agency (EEA) proposed an expansion of the PSR framework in 1999, adding two new categories: Driving forces (D) and Impact (I) (EEA, 1999). The *driving force* indicators describe the socioeconomic needs and motivations that drive human activity. The negative effects of human activities on the system and society

are referred to as *impacts*. Indicators of impact can include ecological and socioeconomic aspects.

The goal of the DPSIR framework is to provide a comprehensive description of a system through the use of appropriate indicators. According to the original EEA (1999) guidelines, all DPSIR indicators should be descriptive and aim to directly measure features of the real world. However, the framework's application has been broadened to include social, economic, and institutional issues. Depending on the subject being studied, the indicators in each category may be related to ecological, economic, social, or governance dimensions, and each category may consider multiple dimensions (Martins et al., 2012). Following the identification of the key indicators, the available data is organized, and procedures to collect missing data for future analysis are suggested. This can help to improve decision-making processes by facilitating communication among stakeholders. The DPSIR methodology has been recently applied for numerous systems, including fishing management (Martins et al., 2012), urban ecological resilience (Zhao et al., 2021), rural sustainable development efficiency (Khan et al., 2021) and microplastic pollution (Miranda et al., 2020). The DPSIR has also been applied to the study of MSW management in municipalities in Brazil (Rodrigues et al., 2018), Tanzania (Kasuva et al., 2018), Maldives (Shadiya and Shareef, 2020) and South Africa (Nyika and Onyari, 2021).

Other methodologies, including the Life Cycle Assessment (LCA), the Life Cycle Sustainability Assessment (LCSA), and the Hazard and Operability study (HAZOP), have also been used to help the integration of social, environmental or economic indicators for stakeholders into their decision-making process in response to the MSWM policy (Ibáñez-Fóres et al., 2019, 2021; Fattor and Vieira, 2019; Ma and Hipel, 2016; Rigamonti et al., 2016; Silva et al., 2020a; 2020b; Aramian et al., 2020). However, there is still a lack of direct and easily self-applied protocols to assist waste pickers cooperatives in assessing their own eco-sustainability.

Macedo (2013) conducted an insightful study to create numerical indices based on the DPSIR framework and evaluate the operational, organizational, and environmental characteristics of sorting and composting plants, as well as pickers' cooperatives engaged in selective collection programs. The evaluation tool took the form of a questionnaire with nine dimensions that were further differentiated into indications of driving forces, pressures, states, impacts, and response for the firms studied. Macedo (2013) successfully applied the survey to identify all of a cooperative's performance indicators in Brazil. Nonetheless, a limitation of that study, as well as the majority of DPSIR surveys accessible in the literature, is the lack of a direct and automatic correlation between the pressure scores and the ensuing states and impacts, as well as with the responses needed for improvement. The entire operation must be done out manually, which is inefficient, very subjective, and highly dependent on the survey's applicator. Additionally, because the DPSIR questionnaire is a tool for the cooperative to improve its own eco-sustainability performance, it would be ideal if their own personnel could administer the questionnaire on a periodic basis, and receive guidance on appropriate actions to take in response to each specific impacted pressure. In this sense, this study proposes a simple and uncomplicated approach for calculating the sustainability indices of waste pickers' cooperatives that gather and process recyclable materials. A case study in a Brazilian municipality displays the DPSIR framework developed in this work.

3. Methodology

3.1. The proposed DPSIR tool

The proposed DPSIR tool was developed using the methodology of the Environmental Company of the State of So Paulo (CETESB, 2020), which publishes the State Inventory of Urban Solid Wastes annually and has developed several quality indices for waste disposal in landfills and

Table 1
Codes and description parameters for Dimension 1 of the DPSIR survey.

(Dm)	1	Location
(D)	D1.1	Proximity to housing clusters
(P)	P1.1	Distance (> 500 m) from urban and environmental protection areas
	P1.2	Legality of location
	P1.3	Visual isolation from the neighborhood
	P1.4	Road, traffic system and access conditions
	P1.5	Distance from water bodies (> 300 m)
	P1.6	Groundwater level (> 3 m)
(S)	S1.1	Quality of life of the neighborhood
	S1.2	Real estate growth
(I)	I1.1	Dust generation
	I1.2	Noise
	I1.3	Acceleration in asphalt depreciation
	I1.4	Presence of vectors and poisonous animals
	I1.5	Real estate depreciation
	I1.6	Pollution or water/soil contamination
(R)	R1.1	Municipal legislation
	R1.2	Public policies
	R1.3	Regulatory agencies
	R1.4	Residents' Association

Table 2
Maximum scores for each dimension and the total value of the DPSIR survey.

Dimension (Dm)	Maximum Score ($\Sigma_{\max}$)
1 - Location	10.0
2 - Legislation	5.0
3 - Waste processed	20.0
4 - Working conditions	20.0
5 - Infrastructure	50.0
6 - Process operational conditions	20.0
7 - Socio-environmental responsibility	5.0
8 - Administrative processes	5.0
9 - Consumption	5.0
Total	140.0

ditches, composting plants, and waste transfer stations. The Brazilian Resolution [CONAMA 313 \(2002\)](#) regarding the national inventory of industrial solid waste was also used to define the nine dimensions (Dm) of the questionnaire: 1. Location, 2. Legislation, 3. Waste processed, 4. Working conditions, 5. Infrastructure, 6. Process operational conditions, 7. Socio-environmental responsibility, 8. Administrative processes and 9. Consumption. A total of 16 driving forces (D), 74 pressure indicators (P), 23 states (S), 35 impacts (I), and 38 responses (R) were listed in the nine dimensions of the survey.

As an illustration, [Table 1](#) details the DPSIR parameters associated with Dimension 1. (Location). The cooperative's proximity to housing clusters is the driving force (D1). Six pressures (P1-P6) were identified, taking urbanistic, environmental, and legal considerations into account. Two states (S1-S2) represent the cooperative's position in this dimension in terms of the neighborhood's quality of life and real estate growth. Six impacts (I1-I6) have been identified, all of which are related to environmental and urban issues. We proposed four possible responses (R1-R4) for mitigating the impacts.

For the sake of brevity, thorough descriptions of the indicators for each of the nine dimensions are included in supplementary [Tables S1-S9](#).

The quantitative assessment of the survey was based on the cooperative's data analysis and the manual input of levels: ☺ (*appropriate*), ☹ (*attention*), and ☹ (*deficient*) in pressure indicators for each dimension. In accordance with [CETESB \(2020\)](#), each pressure level was assigned a numerical value (weight) based on its significance for the assessment. It is worth noting that other parameters and categories may be used depending on the directives and legislation that apply to the cooperative's location (country, state, etc.).

For each dimension, the sum of the score values (Σ_{score}) was compared to the maximum score possible ($\Sigma_{\max}$). As shown in [Table 2](#), the entire survey was valued in a maximum of 140 points, which were subdivided into the nine dimensions based on their importance for the assessment.

Following data entry, the worksheet automatically classified each dimension into one of three levels based on the $\Sigma_{\text{score}}/\Sigma_{\max}$ ratio: Appropriate (☺), Attention (☹), or deficient (☹).

The states (S) in each dimension were classified into three similar levels using the ratio $V/V_{\max}$, where V is the sum of specific pressure indicator scores and $V_{\max}$ is the sum of individual maximum scores. The impacts were classified automatically into two categories (*existing* or *non-existent*) based on their $V/V_{\max}$ values. Similarly, the responses were automatically classified as *required* or *unrequired* based on their $V/V_{\max}$ values.

[Table 3](#) exemplifies the individual pressure indicator scores for Dimension 1 (Location) and the dimension's maximum score (max). Additionally, the pressures affecting each state, impact, and response are indicated (✓) along with their maximum values ($V_{\max}$).

As observed in [Table 3](#), the sum of maximum pressure scores for P1.1 to P1.6 is $\Sigma_{\max} = 10.0$ points, whereas the maximum values ($V_{\max}$) for each state (S1-S2), impact (I1-I6) and response (R1-R4) vary from 2.0 to 9.0 points according to the sum of maximum scores of corresponding listed pressures (✓). The complete lists of scores, $\Sigma_{\max}$ and $V_{\max}$ for pressures, states, impacts and responses of all nine dimensions of the survey are given in supplementary [Tables S10-S18](#).

The rules in [Table 4](#) were applied to each dimension based on the actual value obtained by each indicator and the respective maximum

Table 3
Possible scores and influence of each Pressure (P) on States (S), Impacts (I) and Responses (R) for Dimension 1.

(P)	Scores			(S)		(I)						(R)			
Nº	😊	😐	😞	S1.1	S1.2	I1.1	I1.2	I1.3	I1.4	I1.5	I1.6	R1.1	R1.2	R1.3	R1.4
P1.1	2.0		0.0	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓
P1.2	2.0		0.0		✓						✓	✓		✓	
P1.3	2.0	1.0	0.0	✓	✓			✓	✓		✓		✓	✓	✓
P1.4	2.0		0.0	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
P1.5	1.0		0.0	✓						✓		✓			✓
P1.6	1.0		0.0	✓								✓		✓	
Σ _{max}	10.0		V _{max}	8.0	8.0	2.0	4.0	6.0	6.0	3.0	8.0	8.0	4.0	9.0	7.0

Table 4

Rules to classify the inputs (pressures) and outputs (dimensions, states, impacts and responses) for the proposed DPSIR survey.

Pressures (input)	☹ ☺ ⊗	→ Appropriate → Attention → Inadequate
Dimensions (output)	$\Sigma_{score}/\Sigma_{max} > 95\%$ $50\% \leq \Sigma_{score}/\Sigma_{max} \leq 95\%$ $\Sigma_{score}/\Sigma_{max} < 50\%$	→ Appropriate → Attention → Inadequate
States (output)	$V/V_{max} > 95\%$ $50\% \leq V/V_{max} \leq 95\%$ $V/V_{max} < 50\%$	→ Appropriate → Attention → Inadequate
Impacts (output)	$V/V_{max} < 100\%$ $V/V_{max} = 100\%$	→ Existing → non-existent
Responses (output)	$V/V_{max} < 100\%$ $V/V_{max} = 100\%$	→ Necessary → Unrequired

V = actual value; V_{max} = maximum value
 Σ_{score} = sum of pressure scores in each dimension
 Σ_{max} = sum of maximum pressure scores in each dimension

values to classify the states (*appropriate*, *attention*, or *deficient*), impacts (*existing* or *non-existent*), responses (*required* and *unrequired*), and dimensions (*appropriate*, *attention* or *deficient*).

The quality index (QI) was parameterized from 0 to 100% based on the sum of scores performed by the cooperative in all nine dimensions divided by the sum of maximum scores (140 points):

$$QI = \left(\frac{\sum_{Dm=1}^{Dm=9} Scores}{140} \right) 100\% \quad (1)$$

In its State Inventory of Urban Solid Wastes, CETESB (2020) established two scales for waste quality indices (0 to 70% as *Inadequate* and 71% to 100% as *Adequate*). In this work, an intermediate level (*Attention*) was added to the quality index (QI) to assist the cooperative in prioritizing corrective measures (Responses): QI below 60% corresponding to *Deficient*, QI between 60% and 80% corresponding to *Attention*, and QI above 80% corresponding to *Appropriate*.

An Excel 2021® worksheet was created to account for all previous rules and criteria, with the only action required being the manual assessment of each pressure indicator and application of the appropriate score level (☹, ☺ or ⊗) based on the cooperative's data analysis. The corresponding values (V) for each state, impact, and response are calculated and ranked automatically in accordance with the examples and rules in Tables 3 and 4. The worksheet also calculated the overall Quality Index (QI) automatically.

3.2. Characterization of the study area

This study was carried out in the municipality of Penápolis, which is located in the interior of the state of São Paulo and had an estimated population of 64,098 people in 2021 (IBGE, 2021) and a GDP per capita of R\$ 26,395 (US\$ 4842). In 2010, the city's Municipal Human Development Index (MHDI) was 0.759, ranking it 169th out of 645 municipalities in the state and 383rd out of 5565 municipalities in Brazil. According to the most recent demographic census, 96.7% of urban homes have adequate sanitary sewage, 98.9% have public roads with trees,



Fig. 1. Location of the cooperative under study.

Dimension (Dm)	Dm1	1 - Location		
Driving forces (D)	D1.1	Proximity to housing clusters	Scores	
Pressures (P) <i>input</i> ➡	P1.1	Distance (> 500 m) from urban and environmental protection areas	😊	2.0
	P1.2	Legality of location	😊	2.0
	P1.3	Visual isolation from the neighborhood	😊	2.0
	P1.4	Road, traffic system and access conditions	😊	2.0
	P1.5	Distancy from water bodies (> 300 m)	😊	1.0
	P1.6	Groundwater level (> 3 m)	😊	1.0
	Total		10.0 (100%)	
		Situation		
States (S) <i>output</i> ➡	S1.1	Quality of life of the neighborhood	100%	
	S1.2	Real estate growth	100%	
		List		
Impacts (I) <i>output</i> ➡				
		Actions		
Responses (R) <i>output</i> ➡				

Fig. 2. Results of the analysis of Dimension 1.

Dimension (Dm)	Dm2	2 - Legislation			
Driving forces (D)	D2.1	Corporate legislation	Scores		
	D2.2	Labor laws			
	D2.3	Licensing			
Pressures (P)	P2.1	Legal entity duly established	😊	1.5	Total 5.0 (100%)
input →	P2.2	Employees in compliance with the labor legislation	😊	1.5	
	P2.3	Valid/adequate operational license	😊	2.0	
			Situation		
States (S)	S2.1	Collected taxes	100%		
output →	S2.2	Job creation	100%		
			List		
Impacts (I)					
output →					
			Actions		
Responses (R)					
output →					

Fig. 3. Results of the analysis of Dimension 2.

and 11.2% have adequate urbanization (culvert, sidewalk, asphalt, and curb). The municipality has a Municipal Plan for Integrated Solid Waste Management, which is in accordance with Brazilian Law 12.305/2010 (Brazil, 2010) and acts as a reference for solid waste management measures.

The cooperative under study was founded in 2000, with support from the department of water and sewage of the municipality, aiming to remove the informal collectors from the landfill. The coopera-

tive started to offer better working conditions to the people who used to pick up waste at the landfill, which used to have a low classification by the environmental inspection agency, but which now meets the technical standards of operation. Currently the cooperative works daily with 35 members in a warehouse of 1500 m², with a social support to help them to reintegrate into society. The cooperative collects recyclable materials in 100% of the municipality. In 2018, the cooperative provided environmentally appropriate destination for approxi-

Dimension (Dm)	Dm3	3 - Waste processed	
Driving forces (D)	D3.1	Systematic records	
	D3.2	Amount of rejects generated	
Pressures (P)	P3.1	Systematic records of processed waste	😊 5.0
input →	P3.2	Fraction of rejects from de processed waste: (< 7%); (7-20%); (>20%)	😞 10.0
		Total	15.0 (75%)
States (S)	S3.1	Operational Quality	100%
output →	S3.2	Profit/loss	75%
Impacts (I)	I3.2	Poor process predictability	✓
output →	I3.1	High costs with rejects disposal	✓
Responses (R)	R3.1	National, State or Municipal legislations (fines and penalties)	✓
output →	R3.2	Population participation	✓
	R3.3	Awareness programs	✓

Fig. 4. Results of the analysis of Dimension 3.

Dimension (Dm)	Dm4	4 - Working conditions	
Driving forces (D)	D4.1	Labor infractions	
Pressures (P)	P4.1	Worker Safety	😊 1.0
input →	P4.2	Uniform	😊 1.0
	P4.3	Training and qualification programs	😊 2.0
	P4.4	Refectory	😊 1.0
	P4.5	Toilet bowl	😊 1.0
	P4.6	Washbasin	😊 1.0
	P4.7	Shower	😊 1.0
	P4.8	Lockers	😞 0.0
	P4.9	Changing rooms	😞 0.0
	P4.10	PPE (goggles, mask and gloves)	😊 0.5
	P4.11	Non-cooperated pickers	😊 1.0
	P4.12	Internal sorters	😊 1.0
	P4.13	Drum shifters	😊 1.0
	P4.14	Shredders	😊 1.0
	P4.15	Balers	😊 1.0
	P4.16	Administrators	😊 2.0
	P4.17	Social Services	😊 2.0
		Total	17.5 (88%)
States (S)	S4.1	Professional Quality	96%
output →	S4.2	Quality of life of the worker	77%
Impacts (I)	I4.3	Occupational diseases	✓
output →	I4.6	Severance pay	✓
	I4.2	Insalubrity	✓
	I4.1	Hazardousness	✓
	I4.4	Work accidents	✓
	I4.5	Employee absence due to health reasons	✓
Responses (R)	R4.2	Labor Union audit/inspection	✓
output →	R4.4	Internal Commission on Accident Prevention	✓
	R4.3	Inspection and risk assessment	✓
	R4.5	Ergonomic assessment	✓

Fig. 5. Results of the analysis of Dimension 4.

mately 964 t (26.1% plastic, 48.7% paper, 14.3% glass, 9.9% metal, and 1.1% others), with an average of 100 t of recyclable materials per month. The estimate is that 15% of the total recyclable materials that enter the cooperative are rejects. Although the city population separates waste appropriately, non-recyclable material is still put in the green bags, making sorting and segregation at the cooperative more challenging.

The cooperative is located outside of the city's urban perimeter, surrounded by native vegetation, and close to the city's wastewater treatment station, as shown in Fig. 1.

In order to validate the proposed methodology, a case study was performed by means of technical visits and interviews and application of the DPSIR questionnaire. Five technical visits were conducted between May and July 2019 in the morning and afternoon, accompanied by the cooperative's supervisor, to collect data, photograph the cooperative's processes, structures, machines, and equipment, and administer the questionnaires. The objective was to identify the driving forces and pressures arising from the ineffectiveness of the cooperative, the impacts generated, the state and potential responses that could be taken not only by the cooperative itself, but also by society and public authorities. From the identification of the driving forces, qualitative and quantitative indicators were assessed to point out the aspects that should be implemented for quality improvement.

4. Results and discussion

The driving force behind Dimension 1, *location*, is the proximity of housing clusters, which exerts pressure on the distance from business centers and environmental protection areas (P1.1), legality of the cooperative location (P1.2), visual isolation from the neighborhood (P1.3), road system conditions traffic and access (P1.4), proximity of water bodies (P1.5), and groundwater level (P1.6), as listed in supplementary Table S1. These pressures were assessed and classified as *appropriate* (☺); for this reason, the cooperative received maximum score of 10 points. Therefore, the states in this dimension were *appropriate*, with the quality of life of the surroundings residents and real estate growth. No immediate impacts were recognized and no actions (responses) required. The overall performance for the cooperative in Dimension 1 is shown in Fig. 2.

The driving forces in Dimension 2, *legislation*, are corporate legislation (D2.1), labor legislation (D2.2), and licensing (D2.3). The pressures include the establishment of a legal entity (P2.1), the compliance of cooperative members with applicable legislation (P2.2), and the availability of a valid and adequate operating license for the cooperative's activity (P2.3). These pressures were assessed through the documents supplied by the cooperative and they were all classified as *appropriate* (☺), and for this reason the highest score (5.0 points) was applied. The overall state was thus *appropriate*, with taxes collected and job generation. No impacts were recognized and no responses were necessary. The overall performance for the cooperative in Dimension 2 is shown in Fig. 3.

In Dimension 3, *Waste processed*, the driving forces are the systematic record of processed waste (D3.1) and the amount of rejects generated (D3.2). The cooperative received the highest score, *appropriate* (☺), in the pressure associated to the periodic records in the control spreadsheets (P3.1). Nevertheless, the cooperative had a monthly rejection rate of 10 to 15%, implying poor segregation or selective collection of low-valued waste. Therefore, it was rated as *deficient* (☹) in pressure P3.2. The final score in this dimension was of 15.0 out of 20.0 points. The cooperative's operational quality state (S3.1) is *appropriate*, but the profit/loss state (3.2) is under *attention*, which is critical in determining economic viability. The *existing* impacts are the process's lack of predictability (I3.2) and the high costs associated with rejects disposal (I3.1). The *required* responses are to consult legislation to determine the possibility of imposing fines and penalties on the gen-

Dimension (Dm)	Dm5	5 - Infrastructure		
Driving forces (D)	D5.1	Structural conditions		Scores
	D5.2	Basic conditions		
	D5.3	Processes and equipment		
	D5.4	Waste disposal		
Pressures (P)	P5.1	Perimeter fence or fence	☺	2.0
	P5.2	Gate	☺	1.0
	P5.3	Entrance or guardhouse	☺	1.0
	P5.4	Access control to the installations	☺	1.0
	P5.5	Office	☺	1.0
	P5.6	Support building	☺	2.0
	P5.7	Sorting shed (structure, floor, masonry)	☺	10.0
	P5.8	Energy distribution	☺	1.0
	P5.9	Telephone distribution	☺	1.0
	P5.10	Water distribution	☺	1.0
	P5.11	Sanitary sewage	☺	1.0
	P5.12	Rainwater drainage system	☺	1.0
	P5.13	Atmospheric discharge protection	☹	0.0
	P5.14	Fire prevention and combat	☺	1.0
	P5.15	Rainwater reuse system	☹	0.0
	P5.16	Solar heating installations	☹	0.0
	P5.17	Landscaping	☺	1.0
	P5.18	Receiving silos	☺	1.0
	P5.19	Storage bays	☺	1.0
	P5.20	Storage for shipping	☺	1.0
	P5.21	Heavy waste storage (metal and glass)	☺	1.0
	P5.22	Forklift	☺	1.0
	P5.23	Scales	☺	2.0
	P5.24	Presses	☺	2.0
	P5.25	Platform trolleys	☺	1.0
	P5.26	Manual trolley to transport drums and bags	☺	1.0
	P5.27	Simple Forklift	☺	1.0
	P5.28	System of economy and control of water use	☺	1.0
	P5.29	Energy saving and control system	☺	1.0
	P5.30	Sanitary landfill for rejects	☺	6.0
				Total 45.0 (90%)
Situation				
States (S)	S5.1	Security	100%	List
	S5.2	Administrative facilities	100%	
	S5.3	Basic structure	83%	
	S5.4	Operational structure	100%	
	S5.5	Aesthetics	100%	
	S5.6	Eco-Sustainability	86%	
	S5.7	Safety	67%	
Impacts (I)	I5.3	Poor eco-sustainability	✓	Actions
	I5.4	Occupational hazards	✓	
	I5.2	Operational hazards	✓	
Responses (R)	R5.1	National, State or Municipal Legislation	✓	
	R5.4	Labor Union audit/inspection	✓	
	R5.3	Technology update	✓	
	R5.5	Internal inspections and corporate audit	✓	

Fig. 6. Results of the analysis of Dimension 5.

erator (R3.1), to increase population participation (R3.2), and to implement awareness programs to encourage proper recycling disposal (R3.3). Fig. 4 gives the overall performance for the cooperative in this dimension.

Dimension 4, *working conditions and team organization*, is driven by labor infractions (D4.1), while the pressures are generated by the absence of adequate working conditions (P4.1 to P4.17). The ergonomics and safety practices of the cooperative were mostly observed in this dimension. Despite this, the final score was lowered (☹) in pressures P4.8 and P4.9 due to the lack of lockers and changing rooms in the facilities, as well as in pressure P4.10 for the non-systematic use of personal protective equipment by all employees (☹). The obtained score in this dimension was 17.5 out of 20 points, implying that some impacts do exist, including risks of occupational diseases (I4.3) and work accidents (I4.4), severance pay (I4.6), insalubrity (I4.2), haz-

Dimension (Dm)	Dm6	6 - Process operational conditions	
Driving forces (D)	D6.1	Produced recyclables	Scores
Pressures (P) input →	P6.1	Speed adjustment of the picking conveyor	😊 6.0
	P6.2	Waste segregation	😊 2.0
	P6.3	Primary sorting	😊 2.0
	P6.4	Secondary sorting	😊 2.0
	P6.5	Tertiary sorting	😊 2.0
	P6.6	Hazardous waste sorting	😞 1.0
	P6.7	Waste compaction	😊 2.0
	P6.8	Internal load circulation	😊 2.0
	Total		19.0 (95%)
Situation			
States (S) output →	S6.1	Quality of recyclables recovered	92%
	S6.2	Quantity of recyclables recovered	94%
List			
Impacts (I) output →	I6.1	Low efficiency process	✓
	I6.2	Low quality product	✓
Actions			
Responses (R) output →	R6.4	Inspection	✓
	R6.5	Quality audit and client feedback	✓
	R6.3	Technology update	✓
	R6.1	Professional qualification	✓
	R6.2	Operational training	✓

Fig. 7. Results of the analysis of Dimension 6.

ardourness (I4.1) and absence of cooperative members due to health reasons (I4.5). The state is mostly *appropriate* in professional quality (S4.1), but with *attention* about the quality life of the worker (S4.2). The *required* responses include the inspections by the Labor Union (R4.2) and Internal Commission on Accident Prevention (R4.4), risk assessment (R4.3), and ergonomic assessment (R4.5) to improve working conditions. Fig. 5 gives the overall performance for the cooperative in this dimension.

Dimension 5, *infrastructure*, has four driving forces: structural conditions (D5.1), basic conditions (D5.2), processes and equipment (D5.3), and waste disposal (D5.4). There are 30 pressure indicators (P5.1 to P5.30). The performance of the cooperative was compromised in this dimension due to the absence of atmospheric discharge protection systems (P5.13), absence of sprinklers for fire prevention and combat (P5.14), no rainwater use (P5.15) and lack of solar heating installations (P5.16). The obtained score in this dimension was 45.0 out of 50.0 points. The current states of the infrastructure are partially *appropriate* but with *attention* level in the basic structure (S5.3), eco-sustainability (S5.6) and safety (S5.7). The existing impacts are the poor eco-sustainability (I5.3), occupational hazards (I5.4) and operational hazards (I5.2). The *required* responses include the consultation of national, state, and municipal regulations (R5.1), inspections by the Labor Union (R5.4) or by the cooperative (R5.5), technology update (R5.3) to improve performance in the impaired pressures. Fig. 6 gives the overall performance for the cooperative in this dimension.

Dimension 6, *process operational conditions*, has as its driving force the recyclable material produced (D6.1). The possibility to control the plant capacity through the speed of the conveyor belts (P6.1), waste segregation (P6.2), primary to tertiary sorting (P6.3 to P6.5), waste compaction (P6.7) and internal load circulation (P6.8) were the identified pressures that resulted in maximum scores (😊). On the other hand,

the score was lowered in 1.0 point (😞) in the pressure associated to the sorting of hazardous wastes (P6.6), which was considered inefficient. The total score in this dimension was 19.0 out of 20.0 points. The current state is *attention*, with the quality (S6.1) and quantity (S6.2) of recyclables produced. The existing impacts are the low efficiency in the production process (I6.1) and the low quality of the products (I6.2). The *required* responses include enhancing professional qualifications (R6.1), inspections (R6.4), quality audits and client feedback (R6.5), and operational training (R6.2), as well as implementing available hazardous waste sorting technologies (R6.3). Fig. 7 gives the overall performance for the cooperative in this dimension.

Dimension 7 involves the *cooperative's social and environmental responsibilities*. The driving force is environmental education (D7.1). The pressures include the existence of environmental education programs (P7.1), partnership with local community and non-governmental organizations, NGOs (P7.2) and source reduction and reuse programs (P7.3), which were all classified as *appropriate* (😊) and received the highest score (5.0 points). The state is therefore *appropriate*, characterized by environmental awareness and responsibility (S7.1), and social responsibility (S7.2). No impacts were recognized and no actions (responses) were required. The overall performance for the cooperative in this dimension is shown in Fig. 8.

The analysis performed in Dimension 8, *administrative processes*, identified the driving force composed of plans and controls (D8.1) and economic viability (D8.2). The pressures were the existence of planning worksheets (P8.1), customer audit and loyalty programs (P8.2) and supplier loyalty programs (P8.3) through commitment, respect, and efficient work. They were all classified as *appropriate* (😊) and received the highest score (5.0 points). The state is therefore *appropriate*, characterized by competitiveness (S8.1), and economic sustainability (S8.2). No impacts were recognized and no responses were necessary. The

Dimension (Dm)	Dm7	7 - Socio-environmental responsibility		
Driving forces (D)	D7.1	Environmental education	Scores	
Pressures (P) input →	P7.1	Environmental education programs	😊 2.0	
	P7.2	Partnership with local community and NGOs	😊 1.0	
	P7.3	Source reduction and reuse programs	😊 2.0	
			Total	5.0 (100%)
			Situation	
States (S) output →	S7.1	Environmental awareness and responsibility	100%	
	S7.2	Social responsibility	100%	
			List	
Impacts (I) output →				
			Actions	
Responses (R) output →				

Fig. 8. Results of the analysis of Dimension 7.

Dimension (Dm)	Dm8	8 - Administrative processes		
Driving forces (D)	D8.1	Plans and controls	Scores	
	D8.2	Economic feasibility		
Pressures (P) input →	P8.1	Planning worksheets	😊 1.0	
	P8.2	Customer audit and loyalty programs	😊 2.0	
	P8.3	Supplier loyalty Programs	😊 2.0	
			Total	5.0 (100%)
			Situation	
States (S) output →	S8.1	Competitiveness	100%	
	S8.2	Economic sustainability	100%	
			List	
Impacts (I) output →				
			Actions	
Responses (R) output →				

Fig. 9. Results of the analysis of Dimension 8.

overall performance for the cooperative in this dimension is shown in Fig. 9.

In Dimension 9, *consumption*, the driving forces are the water consumption (D9.1) and energy consumption (D9.2). The pressure P9.1 scored *inefficient* (☹) because of the very low consumption of water (<0.10 m³/dia) to run all process and human activities, while pressure P9.2 scored *attention* (😊) because the relatively high electricity consumption (between 1.205 and 2.400 kWh/month). The total score of the cooperative in this dimension was 1.0 out of 5.0 points. The states are *deficient*, with the risk of economic sustainability (S9.1) and low resource efficiency (S9.2). The *existing* impacts include resource losses (I9.1), infeasibility (I9.2) and poor eco-sustainability (I9.3). The *required* responses are the realization of internal inspections and operational training (R9.1) to verify the insufficient use of water, technology update

(R9.2) and process optimization (R9.3) to improve the performance of the process and reduce the power consumption. Fig. 10 gives the overall performance for the cooperative in this dimension.

Table 5 summarizes the cooperative's results in the DPSIR survey. The dimensions with the highest scores were location (D1), legislation (D2), socio-environmental responsibility (D7), and administrative processes (D8), while the dimensions with compromised scores were waste processed (D3), working conditions (D4), infrastructure (D5), process operational conditions (D6), and consumption (D9). The total score was 123.5 out of 140 points, representing a quality index of 87.5%, which was considered as *appropriate* in the proposed scale.

The significant advantage of the methodology proposed in this study is that once the pressures in each dimension are assessed, the associated impacts, states, and responses are automatically suggested, resulting in a cooperative's quality index. The procedure eliminates subjective in-

Dimension (Dm)	Dm9	9 - Consumption		
Driving forces (D)	D9.1	Water and energy consumption	Scores	
Pressures (P)	P9.1	Water consumption, m ³ /day (0.11-0.29); (< 0.10); (> 0.30)		0.0
	P9.2	Energy consumption, kWh/t (< 1.204); (1.205-2.400); (>2.400)		1.0
input			Total	1.0 (20%)
States (S)	S9.1	Sustainability	20%	
output	S9.2	Resource efficiency		
			Situation	
Impacts (I)	I9.1	Resource losses		
output	I9.2	Infeasibility		
	I9.3	Poor eco-sustainability		
			List	
Responses (R)	R9.1	Internal inspection and operational training		
output	R9.2	Technology update		
	R9.3	Process optimization		
			Actions	

Fig. 10. Results of the analysis of Dimension 9.

Table 5
Summary of the survey for the cooperative analyzed in this work.

Dimension (Dm)	Maximum Score	Score achieved	Relative score	Existing Impacts	Required responses
1 - Location	10.0	10.0	100%		
2 - Legislation	5.0	5.0	100%		
3 - Waste processed	20.0	15.0	75%	I3.2 I3.1	R3.1 R3.2 R3.3
4 - Working conditions	20.0	17.5	88%	I4.3 I4.6 I4.2 I4.1 I4.4 I4.5	R4.2 R4.4 R4.3 R4.5
5 - Infrastructure	50.0	45.0	90%	I5.3 I5.4 I5.2	R5.1 R5.4 R5.3 R5.5
6 - Process operational conditions	20.0	19.0	95%	I6.1 I6.2	R6.4 R6.5 R6.3 R6.1 R6.2
7 - Socio-environmental responsibility	5.0	5.0	100%		
8 - Administrative processes	5.0	5.0	100%		
9 - Consumption	5.0	1.0	20%	I9.1 I9.2 I9.3	R9.1 R9.2 R9.3
	140.0	122.5	87.5%	Quality Index, QI:	Appropriate

terpretation and identifies all indicators that merit additional attention and discussion. As a result, it enables the cooperative to propose highly targeted improvement measures.

5. Conclusions

This paper described a tool designed to assist cooperatives in self-application of a DPSIR survey. A nine-dimensional questionnaire based on the methodology proposed by state and national environmental agencies was created and automated to link 16 driving forces (D), 74 pressure indicators (P), 23 states (S), 35 impacts (I), and 38 responses (R). The findings of a case study allowed for a systemic assessment of a cooperative as well as its surroundings, taking into account a variety of factors. The cooperative under study received high scores for the dimensions Location, Legislation, Environmental responsibility, and Administrative processes, while receiving lower scores for the dimensions Waste processed, Working conditions, Infrastructure, Operational conditions, and Consumption. The proposed evaluation tool allowed for a better understanding of the driving forces, proposing quantitative and qualitative indicators and allowing for the verification of pressures, states, potential impacts, and responses for the cooperative, in order to highlight the aspects that require improvement. The cooperative was deemed to be in appropriate condition, with a quality index of 87.5%. As a result, it was established that the cooperative contributes to the efficient management of solid waste in the municipality, promotes environmental preservation, conserves natural resources and storage space for waste,

improves the quality of life for cooperative members, generates income, and boosts the city's economy. The proposed methodology is intended to be a systematic tool to help all cooperatives of selection of recyclable materials running on a semi-professional level and that need guidance for improvement in their eco-sustainability indicators.

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CRediT authorship contribution statement

Jéssica Patrícia Corrêa Brunhara: Conceptualization, Methodology, Validation, Formal analysis, Investigation. **Karla Gonçalves Macedo:** Conceptualization, Writing – review & editing. **Tapas K. Das:** Writing – review & editing. **Murilo Daniel de Mello Innocentini:** Conceptualization, Investigation, Writing – review & editing, Supervision, Project administration.

Supplementary materials

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